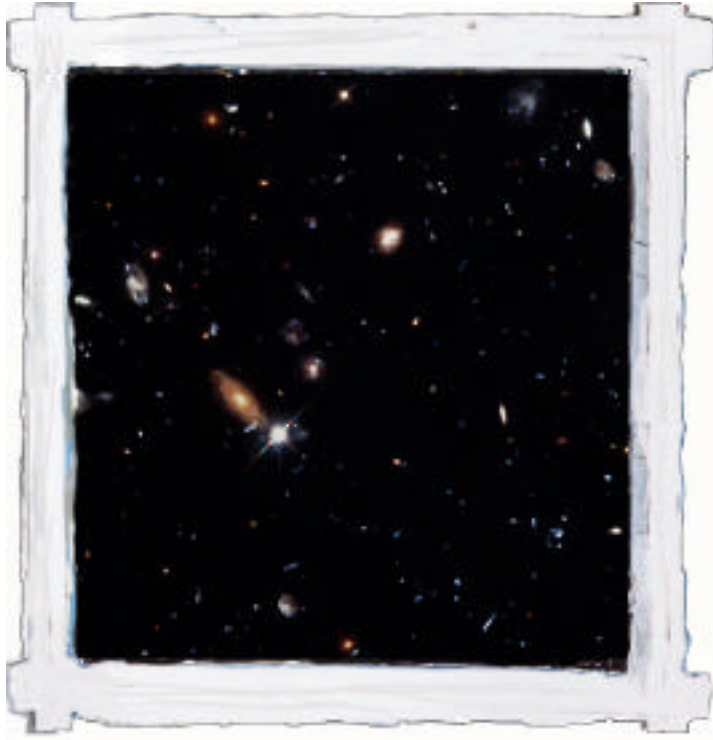




ORIGINS/NGST



"Visiting a Time When Galaxies Were Young"
-from HST and Beyond, AURA

THE NEXT GENERATION SPACE TELESCOPE

Technology Requirements

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The NGST Science Mission

- | **The Early Universe: The First Stars and Galaxies**
- | **Geometry and Chemical Evolution of the Universe: Distant Supernovae**
- | **A broad Origins-related program**
 - **The Evolution of Galactic Structure (the Birth of the Milky Way)**
 - **Understanding Baryonic Dark Matter (Brown Dwarfs, Grav. Arcs)**
 - **Evolution of Stellar Populations in and beyond the Milky Way**
 - **An Ecliptic Plane mini-survey for Kuiper Belt Objects in NIR**
- | **Following *ISO*, *SIRTF*, *SOFIA*, Keck, Gemini with the Thermal IR Option**
 - **Coronagraphic capabilities in TIR for "Jupiter" searches out to 10 pc.**
 - **Imaging & spectroscopy of distant, embedded AGN and star-forming regions.**
 - **Solar system composition studies of outer planets, comets, asteroids**

SCIENTIFIC CHARTER

- **Develop near IR optimized telescope to study origins of galaxies, stars, planets**
 - **Radiatively cooled**
 - **Aperture > 4 meters, diffraction limited at < 2 microns**
 - **1-5 microns required, 0.5 - 20 microns desired**
 - **Cameras and low-medium resolution spectrometers**
- **Go far beyond anything possible with other missions, on ground or in space (Keck, Gemini, ISO, NICMOS, WIRE, SIRTf, SOFIA, SIM...)**
- **Be general purpose observatory for user community**

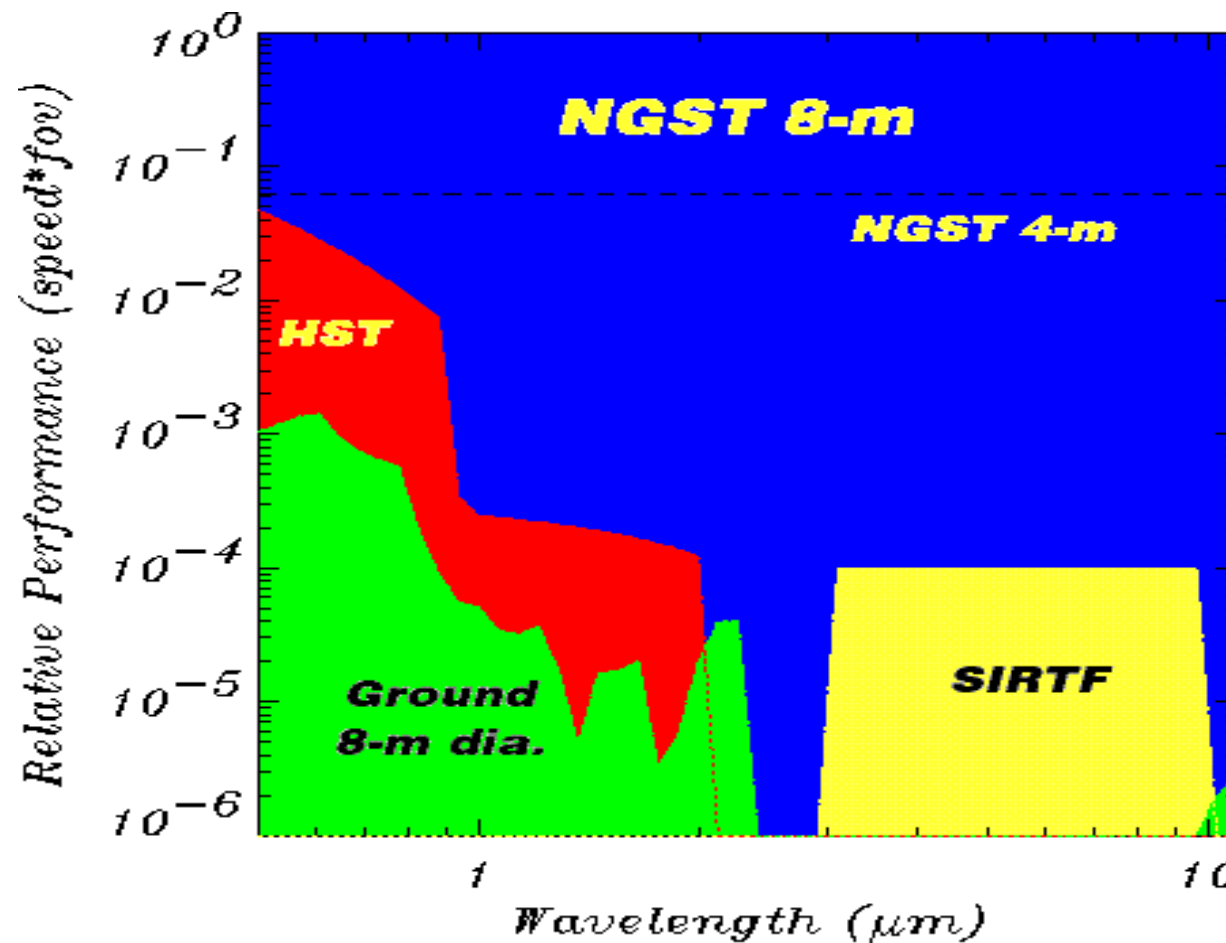
NGST Advantages

- | **0.5 - 1 micron: wide field, high angular resolution imaging**
 - adaptive optics on ground has limited field of view, limited sky coverage, low Strehl ratio
 - some airglow
 - targets are compact, < 0.1 arcsec
 - 3 x larger than HST
- | **1 - 2 microns: imaging and medium resolution multiobject spectroscopy**
 - adaptive optics effective, but ground needs high resolution to see between lines, can't do many objects at once, some wavelengths are blocked
- | **> 2 microns: imaging, spectroscopy except very high resolution**
 - ground based telescope emission very bright
 - atmospheric blockage at most wavelengths
 - 10 x larger than SIRTf

Science and Engineering Goals

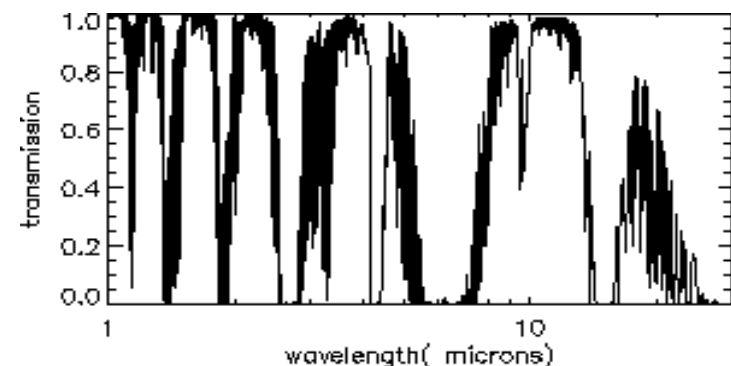
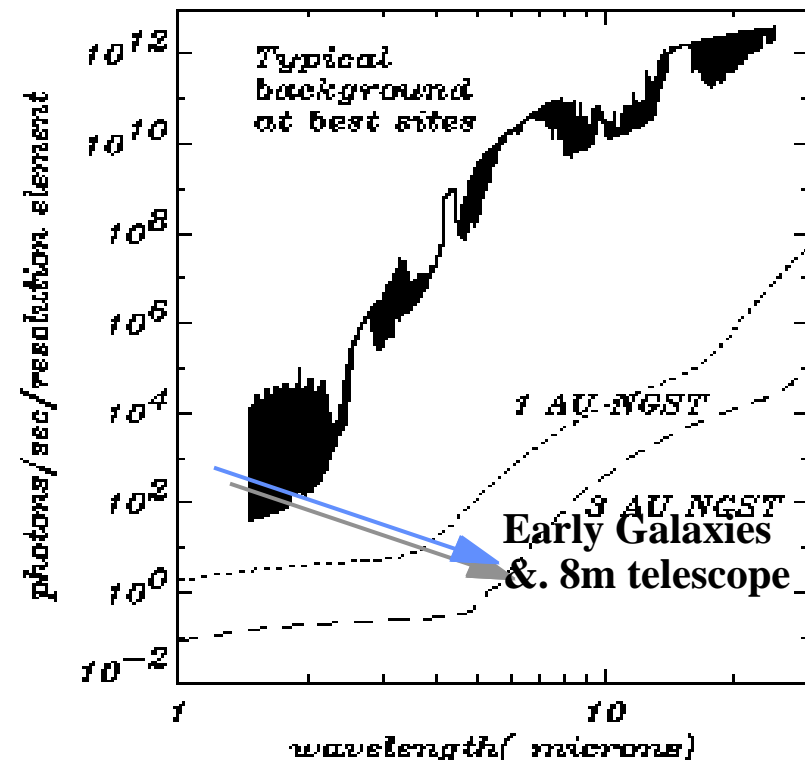
Parameter	Science Floor (Dressler)	Stretch Goals
Wavelength Range	1-5 μm	0.5 - 30 μm
Angular Resolution	Diffraction-limited at 2 μm	Diffraction-limited at 0.5 μm
Aperture Diameter	> 4 m	> 8 m
Sensitivity	Zodi-limited at 1 AU	Cosmic IR background limited
Lifetime	> 5 years	10 years
Instruments	Wide Field Camera/ Spectrometer	Add visible, TIR camera/ Spectrometer and coronagraph

An 8 m NGST Provides $> 10^3$ Speed Improvement from 1-10 μm



NGST Rationale vs Ground

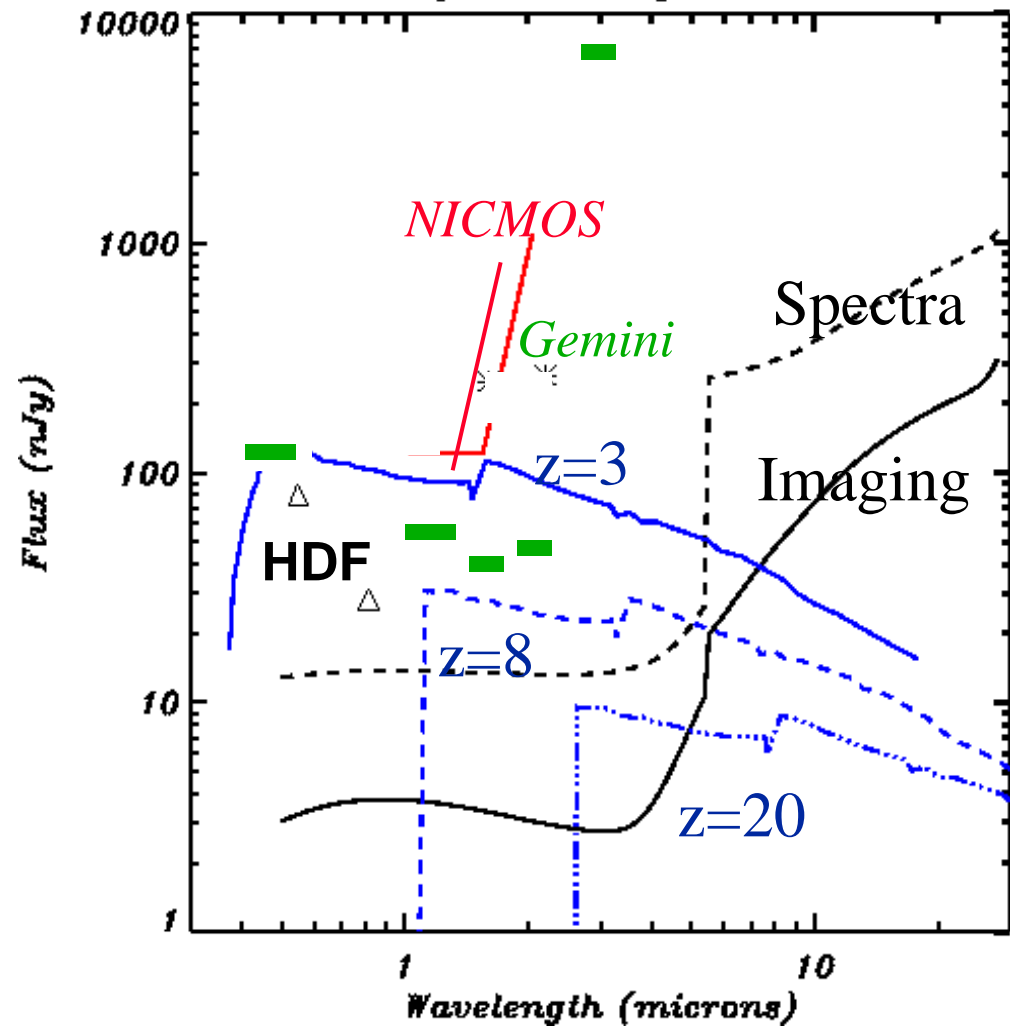
- >4m, telescope is required to get the sensitivity required to probe the origins of stars and galaxies at large redshifts (early days).
- A cooled telescope provides 10^2 to 10^8 lower background and perfect transparency. Cooling to deep space breaks the IRAS/ISO "telescope-in-a-bottle" paradigm and permits larger apertures with no additional weight penalty.



Star formation in the Early Universe

Early Protogalaxies

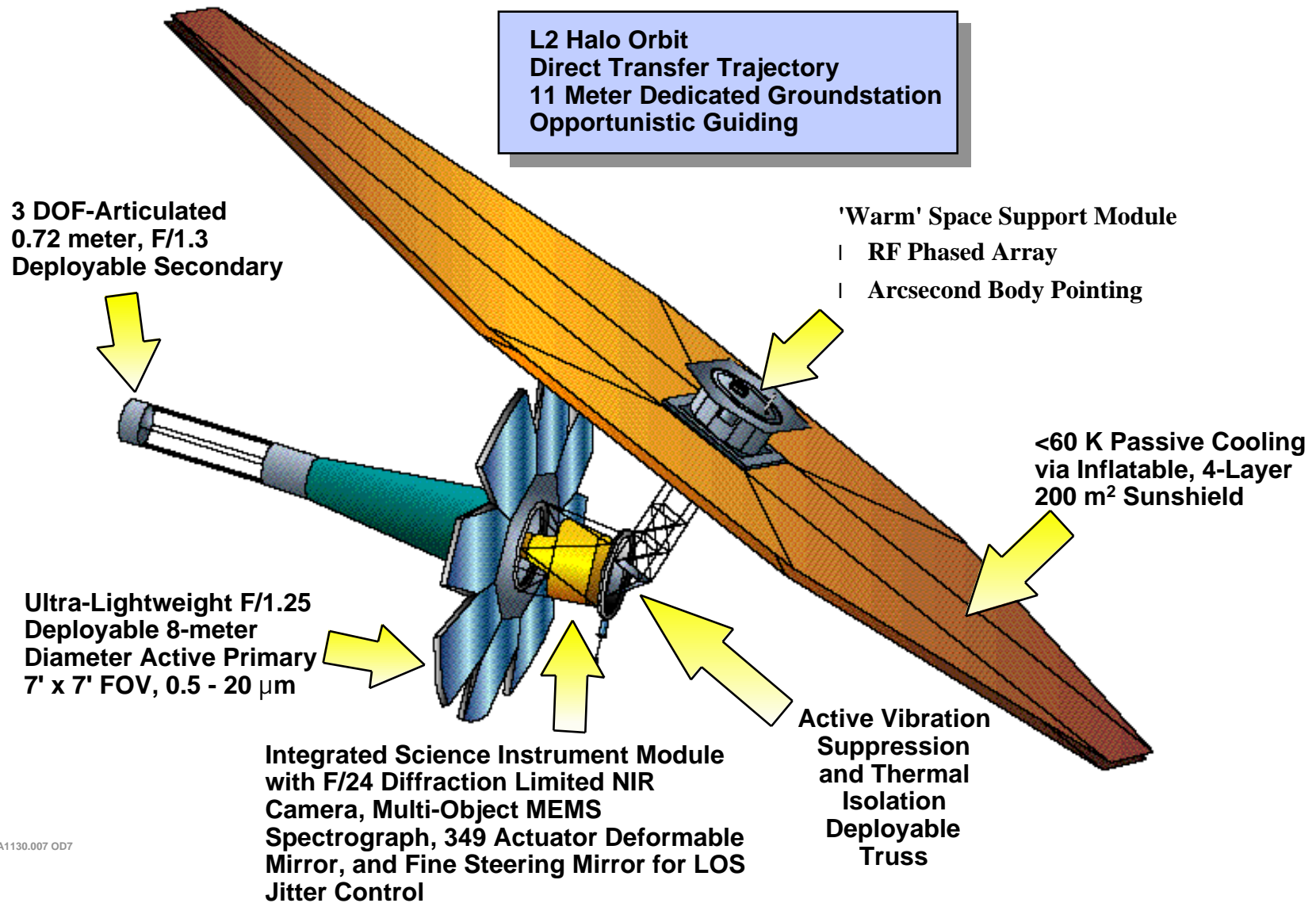
- 3 nJy sensitivities in imaging (10^4 s) for 0.06 sq arcsec.
- ~10 nJy sensitivities in low res., multi-object spectroscopy
- $1 M_{\text{sol}} \text{ yr}^{-1}$.
- 25 Myr
- • = 1



NGST Orbit Options

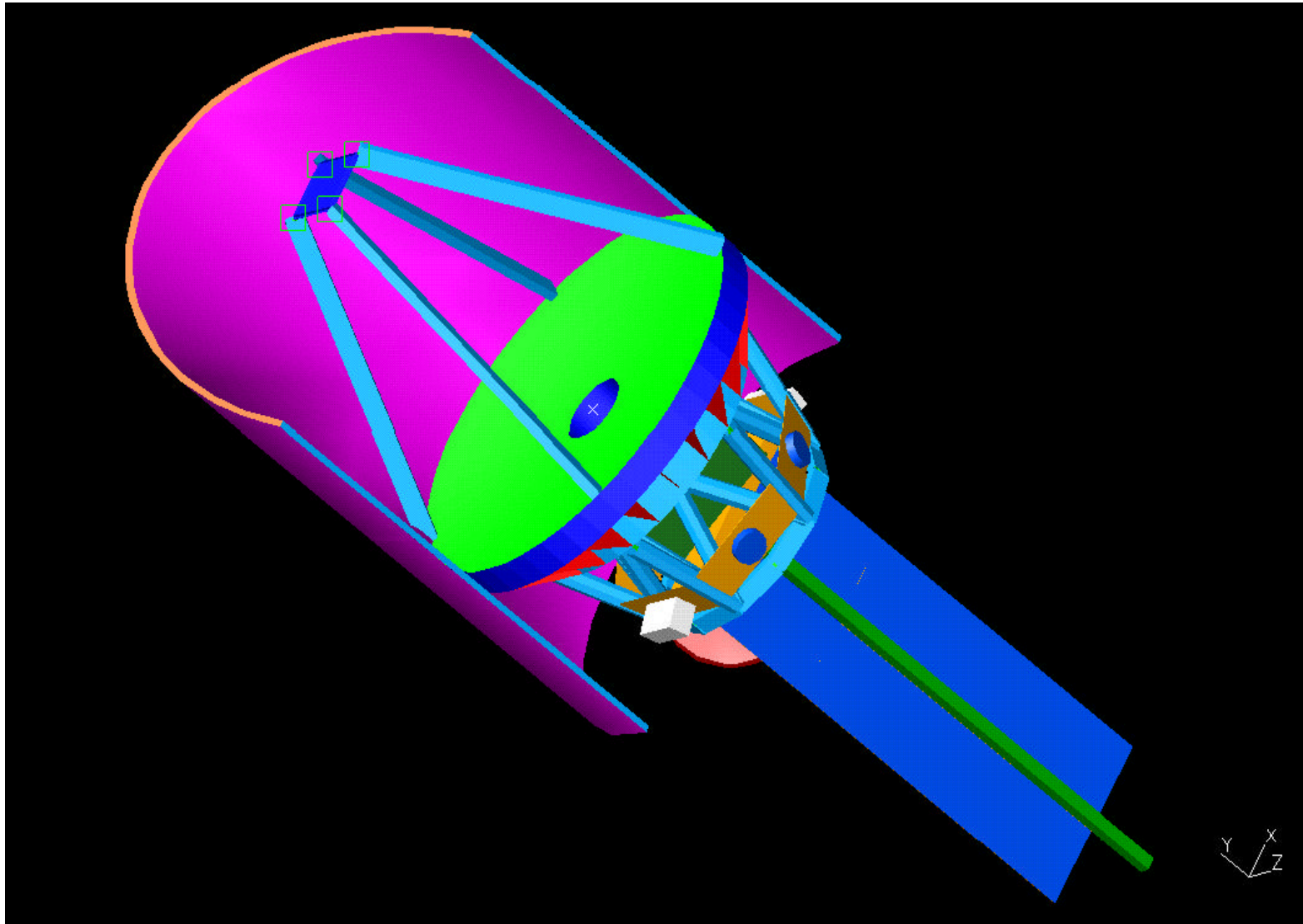
- | **Heliocentric 1 x 3 A.U.**
 - **Communications Requirements are Challenging**
- | **“Drift-Away” Orbit (a la SIRTf)**
 - **Trade Between Communications System and Propulsion**
- | **L2 Libration Point**
 - **Lunar Swingby (No Phasing Loops)**
 - **Launch Window Less Restrictive (1 Day per Month)**
 - **Operations Become More Complex**
 - **Repeated “Near-Earth” Passes**
 - **Direct Transfer to L2**
 - **Least Restrictive Launch Window (About 27 Days per Month)**
 - **Least Complex Operationally**

8-Meter Conceptual Design

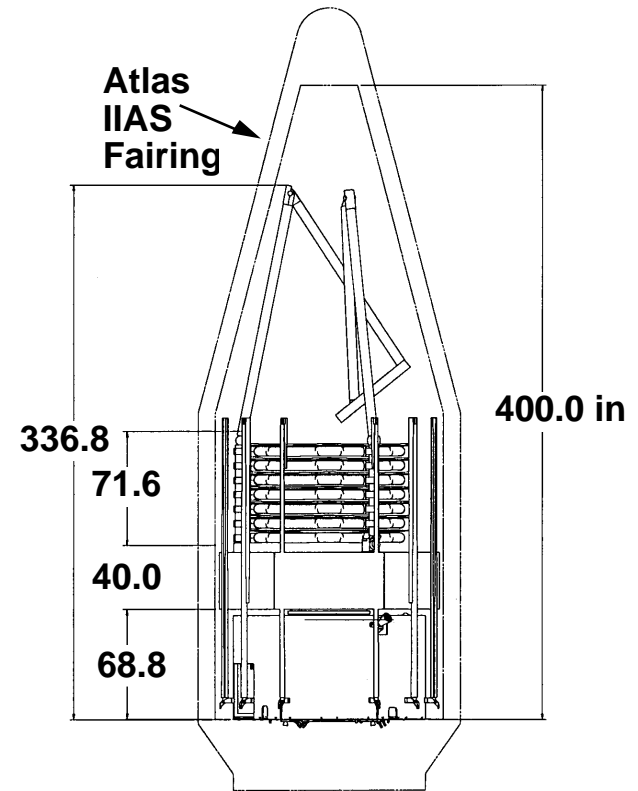
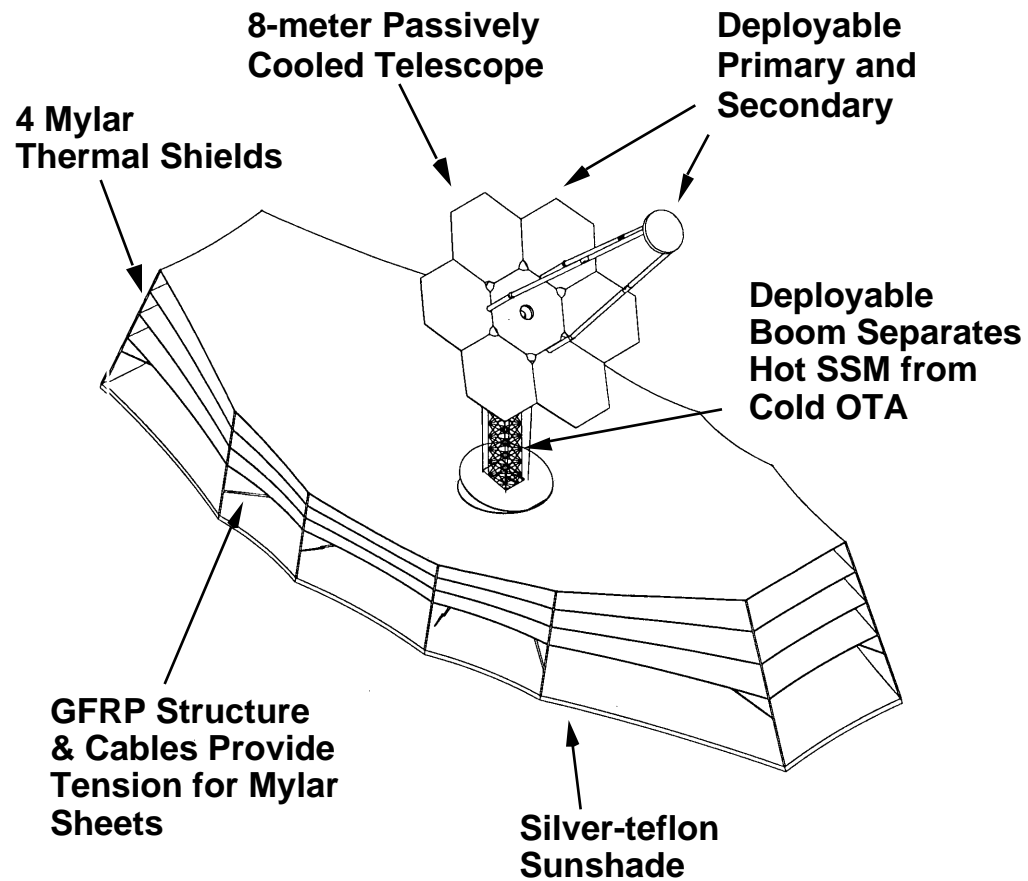


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L-M NGST Design Concept



HARD Configuration - TRW concept



LAUNCH VEHICLE TECHNOLOGIES

- **Lower cost to orbit - a primary concern**
- **Many options coming in commercial capabilities**
- **Chance of international contribution, e.g. Ariane**
- **Larger payload volume could avoid need to deploy, or enable larger telescope - BUT beware cost implications**
- **Greater C3, could enable deeper space mission outside or above zodiacal cloud, more imaging sensitivity with smaller telescope**
- **Lower vibration and acoustic loads, allows fragile mirrors (glass, SiC)**
- **Space Tug from LEO to L2 or deep space, allows LEO checkout of deployment, could reduce risk - but what cost?**

SPACECRAFT BUS TECHNOLOGY

- **SMALLER, FASTER, CHEAPER!**
- **Low weight, high performance avionics leave space for telescope**
- **High data rate communications, could be enhanced/enabled by laser comm, big steerable dishes, higher frequency, big phased arrays**
- **Light weight structures for a light weight telescope**
- **Cheap, light attitude control system**
- **Bigger, better computers for data processing, compression, autonomous operation, help with mirror figure control**

SUNSHIELD TECHNOLOGY

- **First large radiative cooler in space, special deployment problems**
- **Deep cooling for telescope needed: $T(\text{telescope}) < 600 \text{ K}$, implications for layer numbers, spacings**
- **Cleanliness issue: outgassing, dust**
- **Stiffness, interaction with attitude control system**
- **Response to solar radiation torque, or control of the torque**
- **Degradation by solar UV, cosmic rays**
- **Overheating or damage to shield if attitude control is lost**
- **Possible first use of a large inflatable structure**
- **Many configuration choices: circular torus, kite with ribs, ...**
- **Many deployment choices: inflation, astromasts, rods and pulleys**

MECHANICAL ISOLATORS

- **Challenge: separate telescope thermally and mechanically from spacecraft, but provide control, cooling, data, power, etc.**
- **Deployed trusses in space - do they creak and groan at milliarcsecond level?**
- **Reaction wheels main known vibration source, could have own isolation**
- **Standard cables to telescope are stiff, thermally conductive**
- **High Tc superconductor cables could avoid heat conductance to telescope, need development**
- **Possible fiber optics power supply, data, and commands**
- **Need to filter out vibrations: where should the isolation be?**

ATTITUDE CONTROL SYSTEM

- **Low vibration reaction wheels simplify system design**
- **Jets are needed for unloading wheels, but need non-contaminating version, e.g. hydrogen jets, or proof that hydrazine is clean**
- **Slew rate can be slow; no scientific requirement for fast slew**
- **Need qualified cryogenic tip-tilt mirrors, maybe in pairs to keep focal plane from tilting too**
- **Cryogenic gyros and wheels would give option to control telescope directly, instead of relaying position from warm spacecraft**
- **Need work on star sensor compatible with instrument focal plane, or using science instrument sensors**

TELESCOPE MIRROR TECHNOLOGY

- **Require 4 m aperture, asking for 8 m, with diffraction limited performance at $2\ \mu$ and reasonable performance at $0.5\ \mu$**
- **Figure of merit: A/θ^2 where A is area, θ is angular resolution**
- **Can't be too floppy, vibrations must damp soon after slews**
- **Must survive launch vibration, attacks from micrometeoroids**
- **Can't have too many fine scale bumps, or even deformable mirror can't repair the wavefront**
- **Really good wavefront enables looking for BIG planets near stars**
- **Thermal gradients large (40%), induced figure errors large, may not be stable**
- **Segment edges and radii of curvature must match**
- **Don't know frequency of adjustment, must tolerate many cycles**

MIRROR ACTUATORS

- **Mirror deployment and latching**
- **Dozens of coarse (~ 6 mm stroke) actuators**
- **Hundreds to thousands of fine (few nm resolution) adjusters**
- **~Zero power dissipation in holding state**
- **Need to know effects of local heating on mirror**
- **Perhaps many thousands of operations - stability is unknown**
- **Tradeoff on location: primary mirror, deformable quaternary**
- **Combine coarse and fine actuators?**
- **Cold actuators hard to lubricate**
- **Piezoelectric, magnetostrictive materials change properties with temperature**
- **Should function at all temperatures to save on test costs**

SECONDARY MIRROR

- **Support structure wobbly, gives very low frequency vibration modes, and has major temperature gradients**
- **Secondary support tower must not block beam**
- **Need excellent stability - secondary comes before magnification, so image scale is very small**
- **Need fine adjustment in ~5 degrees of freedom, to set focus and minimize aberrations**
- **Prefer to avoid active figure control of secondary**
- **Want to avoid active position control and metrology, use minimum extra parts**

WAVEFRONT SENSORS AND ADJUSTMENT

- **Phase Retrieval**, uses in and out of focus star images from science instruments, and a lot of computer time
- **Shack Hartman**, uses microlens arrays to make multiple measurements of wavefront tilt angle
- **Point Diffraction Interferometer**, standard lab method, uses interference of beam with a filtered beam to show mirror figure fringes
- **Interferometers** to get piston errors at segment joints
- **Automated adjustment algorithm**, or human in the loop?

SCIENTIFIC INSTRUMENT OPTICS

- **Efficient packaging with low aberrations, high optical efficiency**
- **Provide cold stops (baffles) for stray light**
- **Provide location for fast steering mirror and deformable mirror**
- **Provide location for attitude control star sensors (possibly scientific instrument sensors)**
- **Provide for wavefront sensors, using science instruments or otherwise**
- **Want commandable pixel switches for input to spectrometer: digital micromirror device, large ($>1000 \times 1000$) format, cryogenic operation, good control electronics**
- **May need focus actuators, will need filter wheel mechanisms, etc.**
- **Improved dichroic and bandpass or tunable bandpass filters always beneficial**

DETECTORS

- **Figure of Merit: $N_{\text{pixels}}/\text{NEP}^2$, where NEP is Noise Equivalent Power in presence of photon background, dark current, cosmic rays ($4/\text{cm}^2\text{sec}$), read noise**
- **Want largest affordable arrays, up to 8192×8192 at 1-5 microns**
- **InSb for 0.4-5 microns, at 30 K.**
- **CCD's for 0.4-1.1 micron, will they work at 30 K?**
- **HgCdTe for 5-10 microns, need 20K?**
- **Si:As for 5-26 microns, need 6-7 K (very important number!)**
- **Ge:Ga for 40-120 microns, needs 1.4 K (not in stretch goals)**
- **Bolometers for longer wavelengths, need 0.05 K**
- **Cosmic rays limit exposure times, require repeated observations, some fancy data processing**

COOLER TECHNOLOGIES

- Assume radiative cooling gets telescope cold enough
- Radiative cooling probably enough for InSb at 30 K
- Create Reverse Brayton Cycle turbo coolers under development
- Hydrogen sorption pumps under development at JPL for ~7 K
- Helium sorption pumps possible as well
- Stirling cycle coolers work, but vibration must be reduced by balancing, or active or passive isolation
- Lower temperatures need special work, aren't required for core science

COMPUTERS ONBOARD

- **Current generation of rad-hard microcomputers and Digital Signal Processors may be enough, but general purpose supercomputer is under development at JPL**
- **Autonomous operations, no time critical schedules at L2 or in deep space, could reduce staff costs**
- **Computer aided mirror control could raise observing efficiency, improve performance, using iterative control algorithm**
- **Computer could do on-board removal of cosmic ray hits on detector**
- **Large data volume from 100,000,000 pixels, multiple exposures, needs good I/O hardware for detectors and computers**
- **Optimized data compression enables deep space operation**
- **Computer could monitor image quality degradation from vibration, mirror adjustment shifts, and take autonomous action**

SUMMARY

- **NGST technology development enables new science, new configuration choices**
- **Detectors just as important as telescope**
- **Develop first, choose when ready**